Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava
číslo 1, rok 2008, ročník LI, řada hutnická
článek č. 1420

DIFFERENCES OF CONCEPTS OF ULTIMATE MIMIT STATES OF SOILS AND ROCKS

P. KOUDELKA[1]

[1] *Institute of Theoretical and Applied Mechanics ASc. CR; v.v.i., Prague, Czech Republic, koudelka@itam.cas.cz*

ABSTRACT: The paper presents a detailed analysis of the problem of fundamental theoretical incorrectness of contemporary limit state theory in geotechnics, using partial material factors and statistical definition of material characteristic values for ultimate limit state designs. In conclusion the author formulates the fundamental principles of modern design concept (ultimate limit state design) in geotechnics corresponding to the present state-of-the-art.

KEY WORDS: Ultimate limit states, characteristic values, statistical definition, partial material factor.

1. INTRODUCTION

This paper has been inspired by in my opinion no consciousness on the fundamentally different concepts of ultimate limit states in geotechnics between EC1-1 "Eurocode 1 - Basis of design and actions on structures-Part 1:Basis of design" and EC7-1 "Eurocode 7 - Geotechnical design - Part 1: General rules" [3] on the one hand and the Czech standard ČSN 73 0031 "Structural and subsoil reliability-Basic requirements for design" of 8th Dec.1988 (in force since 1st Jan.1990) [1], ČSN 73 1001 "Subsoil under shallow foundations" [2] and other Czech standards on the other hand. This ignorance was manifested even in a renowned paper at a professional event, which has resulted in this more detailed examination of the problem.

In the framework of our research, detailed and comprehensive analyses have been made concerning the processes of slope stability analysis, theoretical foundations of earth pressure computation and shallow foundations [4,5] as well as pile foundations analysis. The results achieved so far have shown that the difference of concepts results in significantly different designs. In 2005 a big, really universal meeting took place in Dublin, viz. the IWS Dublin 2005 - Evaluation of Eurocode 7-1, organized by ISSMGE/TC23 (Limit State Design) the results of which have proved practically the inadequacy of theoretical concept and design according to EC7-1 and their unacceptability for the solution of all basic geotechnical problems.

It is generally known that most of our geotechnical standards as well as EC7-1 are based on the Limit State Design theory. This may - and probably does - arouse an erroneous impression that the theoretical foundations of both systems of the standards (EC7-1 and ČSN 73 0031) are identical. Moreover, this impression is supported by the fact that in other fields of structural design (concrete, steel, masonry, timber and other structures) the theoretical concepts of ultimate limit states of EC7-1 and ČSN do not differ. Thanks to the above mentioned paper I have realized how little - if at all - our professional geotechnical public perceives or knows the fundamental difference between the concept of Ultimate Limit State Design of the Czech geotechnical standards and the concept of ULSD of the Eurocodes incl. EC7-1.

2. THE HEARTT OF THE PROBLEM

The basis of the Ultimate Limit State Design (hereafter ULSD) problem and its application to geotechnical design consists in the very substance of the Limit State Design (hereafter LSD) theory. This theory was devised for the structures designed in *elastic region* (state) at the beginning of the 50s of the 20th century with the purpose of introducing probability to the theory of structural design. As we know, the probabilistic methods applied are not purely probabilistic, but merely quasi-probabilistic. Further development and application of this theory in the 60s and awards took place practically only in Eastern Europe in the framework of the Council of Mutual Economic Assistance (CMEA, known also as COMECON) by means of which Soviet Russia controlled its satellites. Western Europe considered and discussed the application of the LSD theory approximately from the 70s in the framework of the discussion of the EUROCODES system. As we know the development and the preliminary introduction of EUROCODES outside geotechnics took more than 25 years, in the case of geotechnics 30years and their introduction as fully applicable standards has not been completed as yet. On other continents the LSD theory is applied only exceptionally.

In general it is possible to access the application of LSD theory to design of materials in elastic region (concrete, steel, etc.) as successful, although particularly at the beginning the LSD was refused and the probabilistic approach can be applied also to other theories.

In former Czechoslovakia (act. the Czech Republic) the very first standard based on LSD theory was the afore mentioned ČSN 73 1001 „Subsoil under Spread Foundations" of 30 March 1966, i.e. - issued 10 years before the first discussions on EC7 started in Western Europe. This standard as well as other geotechnical standards are linked with the fundamental standard ČSN 73 0031 of 9 September 1977 which introduced the LSD in general.

Theoretical as well as practical problems connected with the solution of specific geotechnical problems (poor design effectiveness in most cases) arose from the very beginning in both parts of Europe and have continued to the present day – a fact confirmed by unceasing general discussions of fundamental problems (such as partial material factors). What is the actual cause of the problem that has not been solved successfully for several decades?

The cause must buried deep. Therefore, let us look at the fundamentals of the LSD theory. Its methodological basis is the replacement of probabilistic quantities with a system of partial factors obtained from statistical files and replacing actual statistical quantities. These partial factors are used for characterization of individual limit states of structures. If simplified they can be broken up into four groups:

a) partial factors of loads and quantities related thereto,
b) partial factors of geometry and quantities related thereto,
c) partial factors of material properties,
d) partial factors of resistance (analogy to safety factors).

The application of partial factors introduces into the analysis the principle of superposition, i.e. the *real or nearest-to reality* model is replaced with other, *more dangerous* models with the supposition of proportionate behaviour. It is generally known from general mechanics that the application of the principle of superposition in analyses is applicable only to the computation of *elastic states* (mathematically to *linear functions*). This requirement may be complied with fully or more-or- less fully by all structures *except for geotechnical structures*. There are no fundamental problems in geotechnics which would be linear; p*ractically all geotechnical problems are non-linear*.

Let us concentrate now only on the first group of limit states – ultimate limit states (ULS) – and assess the permissibility of application of the individual types of coefficients to non-linear problems according to the principles of mechanics. We can say that the load and resistance factors (given sub a) and d) above), i.e. e.g. increased load and required resistance reserve, are external factors (requirements imposed on the structure) and influence the final results of non-linear problems and their assessment, but do not influence the actual behaviour of model soil and rock mass. On the other hand, the factors of geometry and material properties (given sub b) and c) above) change the most probable model of the actual mass to a not very probable or almost improbable model of the mass, i.e.

to a different model mass with different behaviour. The behaviour of the numerical model using the factors sub b) and c) differs substantially from the behaviour of the actual soil and rock mass and its real reliability is not directly proportionate with the factors used and cannot be derived from them (compare Fig. 1a, 1b).

The factors of geometry are often circumvented in practice by direct definition of analytical shapes of the mass (geotechnical structure) and their influence usually is not so fundamental as the influence of material factors. However, the application of the factors of material properties is of fundamental significance and is impermissible in non-linear problems according to the principles of mechanics. Naturally, the question arises how it is possible that geomechanics does not respect the principles of general mechanics and who has started it. The initiator of this

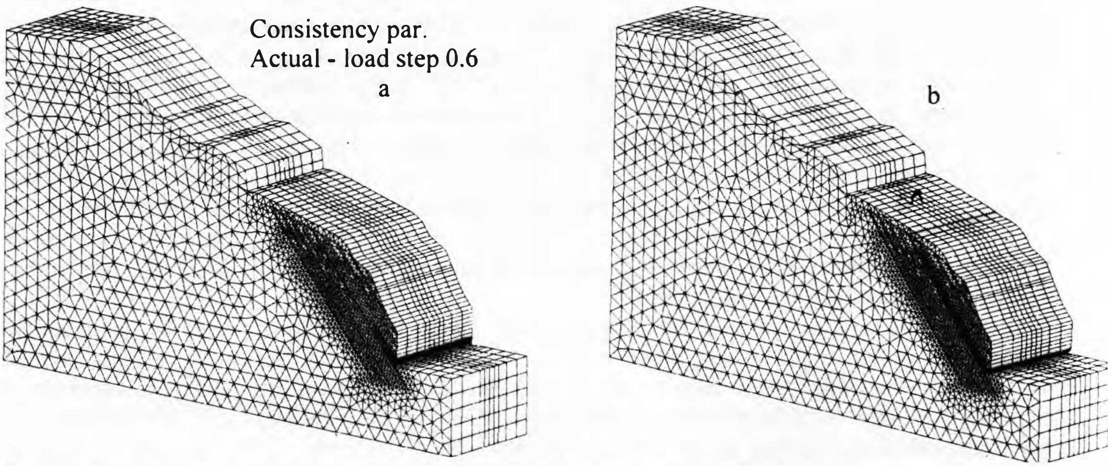

Fig. 1: Coefficient of plasticity (consistency) λ in a 3D model of a stratified rock mass (approx. h=25 m, Prague, Chotek highway, Pier No. 10) – Model state for critical load according to EC7-1, App.2: **a**) Model with the most probable material values – loading stage 0.6 g – beginning of promontory foot plastification. **b**) Model with derived material values according to EC7-1, App.2 – loading stage 0.575 g – maximal load before promontory collapse – see the plastification of the whole shear area under lower load.

error, fatal for the whole geomechanics for several decades, probably is Brinch Hansen (Denmark) who published the first known article on the introduction of the LSD theory to geomechanics in 1955.

It follows that both Czech standards (ČSN 73 0031, ČSN 73 1001) and EC7-1 have common theoretical foundations based on a fatal error and failure to respect the principles of mechanics. In spite of that the concept of both systems of standards differ substantially.

3. DIFFERENCE OF CONCEPTS OF CZECH STANDARDS AND EC7-1

In the mutual comparison of both systems of standards the differences in the values of partial factors used is most obvious at first sight. However, these differences are not most substantial and in case of partial material factors they arise to a certain extent from the different definitions of "standard" (ČSN 73 0031) and "characteristic" (EC7-1) physical values of the properties (of soils and rocks) from which the design values are derived in both concepts. *The different definitions of "characteristic" and "standard" values of material properties* are the foundation of the theoretical difference of numerical model according to EC7-1 and ČSN, although the process of derivation of design values in both systems is the same, i.e. the values of physical properties are divided by partial material factors. Let us concentrate only on the values of physical properties of the materials of geotechnical structures and the process of derivation of their design values.

The standard material values for the field of construction are defined in ČSN 73 0031"Structural and subsoil reliability - Basic requirements for design". It is significant that in the very name of standard the subsoils have not been included in the concept of structures, but are mentioned separately. This characterizes significantly the concept respecting the *different character of natural granular materials* (incl. their behaviour) and man-made materials and structures consisting of individual members incl. their behaviour. The standard values of material for structures are defined in Cl.2.1 as follows: "*The fundamental parameters of the material are standard values of strength R_n. The probability guarantee P_{Rn} of the standard value of the strength of built-in material must equal at least 0.95.*" The standard values of geotechnical materials are defined in Cl.2.6 as follows: "*The standard value of subsoil characterisation or parameter describing the co-operation of foundation with the subsoil is determined as a rule as the mean value of examined quantity*", i.e. with the probability guarantee of 0.50 .

In the Eurocode system, the fundamental theoretical design concept is determined in the fundamental parts EC0 and EC1, but it does not differentiate the design of structures of man-made materials consisting of individual members and the structures of natural materials. EC0 defines the *characteristic values of materials uniformly* as the *values providing the guarantee that the probability of occurrence of the less favourable value does not exceed 5%* which is an inverted formulation of the same requirement (95% occurrence of a more favourable value) provided in the Czech standards for building structures *outside geomechanics*.

EC7-1 provides further definitions in Cl. 2.4.5.2, paras (2), (8) and (11) which actually give two definitions of characteristic values:

a) in the cases of sufficient statistical data (para.11) it provides a definition in accordance with the definition given ads follows: "If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%."
b) generally, however, also definition of para (2) applies, namely "The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of value affecting the occurrence of the limit state."

4. CONCLUSIONS

a) The number and formulation of EC7-1 definitions reveal the obvious uncertainty of their formulators as well as the paradox of the definitions. In the cases of good quality and detailed data necessary for statistical evaluation the characteristic values are to be determined in accordance with the statistical definition, i.e. very conservatively, while in the cases of unsatisfactory knowledge of soil and rock masses the characteristic values may be selected practically arbitrarily. With regard to the requested effective designs, this concept practically transfers the whole responsibility to the designer.
b) The analyses neglect the vague definitions ad 3b) and consider the definition ad 3a) representative of EC7-1.
c) The difference in the definitions of characteristic values necessarily results in considerable differences in the effectiveness (conservative character) of ensuing designs influenced only secondarily by partial material factors (derivation of design values). The design based on the ČSN concept are significantly more effective (optimistic).
d) The adoption of EC7-1 without the real (with only formal) National Document would result in substantial long-lasting economic losses due to superfluous and wasted funds invested unnecessarily in foundations.
e) On the contrary, the opportunity provided by the introduction of a new geotechnical standard should be used not only for the preservation of the contemporary (high on international scale)

standard of geotechnical standards, but also for the introduction on a more advanced, modern concept of geotechnical design towards which the most advanced countries (e.g. Japan) seem to be heading. This concept represents the elimination of partial material factors and the formulation of a new concept of general resistance factors (safety factors).

5. ACKNOWLEDGEMENT

The paper is based on the results of research projects of the Grant Agency of the Czech Republic No. 103/2005/2130 and the Grant Agency of the Czech Academy of Sciences No. IAA 2071302. The author would like to express his thanks for this financial support of his research.

6. REFERENCES

[1] ČSN 73 0031 *Structural and subsoil reliability.Basic requirements for design.*Ed.ÚNM (1988), ps.22.

[2] ČSN 73 1001 *Subsoil under shallow foundations.* Ed.ÚNM (1987), ps.75

[3] EN 1997-1 *Eurocode 7: Geotechnical design - Part 1: Geotechnical rules.* Ed. CEN (2004), ps.155.

[4] Koudelka P. (2006a): Similarity of shallow foundations according to ČSN 73 1001 (#355). Proc.ext.abs 12th NC Engineering Mechanics 2006, Svratka, ITAM ASc. CzR, J. Náprstek - C. Fischer ISBN 80-86246-27-2, pp.170-1.

[5] Koudelka, P.(2006b): Numerická analýza únosnosti plošných základů podle ČSN 73 1001.. Proc. 34th NC Foundations – Brno 2006, Brno (Czech Republic), Akademické nakladatelství CERM, s.r.o. Brno, J. Jettmar, ISBN 80-7204-478-8, pp.15-20.